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Advancing Geothermal Potential in Wallonia (Belgium): Insights from Seismic Investigations of Dinantian Carbonates

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ABSTRACT

In response to climate and environmental challenges, the Walloon government is committed to achieving carbon neutrality by 2050 at the latest (including a 95% reduction in greenhouse gas emissions compared to 1990 levels). This goal is based on a progressive emissions reduction trajectory, with an interim target of a 55% reduction in greenhouse gas emissions by 2030 compared to 1990.

To achieve its energy goals, Wallonia will need to adopt geothermal energy on a broad scale and initiate the development of this renewable sector within the region. Currently, geothermal energy represents only a small fraction of the energy mix, even though resources are available in the Sambre-Meuse valley for deep geothermal applications and across the entire region for shallow geothermal systems. Its use aligns fully with the energy transition currently underway in Wallonia.

To assess the geothermal potential in Wallonia, gathering primary subsurface data remains essential. A pivotal part of this process involved seismic data acquisition under the DGE-ROLLOUT project (Interreg North-West Europe), completed in October 2023. This initiative generated several new cross-border seismic profiles, which have substantially reduced geological uncertainties, particularly along the BE/GE and BE/NL borders. These data supported the integration of mapped areas of the primary geothermal reservoir target, the Dinantian formation, and fostered knowledge sharing about potential geothermal aquifers.

In Wallonia, the Geological Survey of Belgium (GSB) conducted 63.5 km of seismic surveys across Namur's eastern and western regions in December 2022 called GEOCOND 22, focusing on the extent of Dinantian limestones beneath the Midi-Eifelian Fault . Findings from this survey shed light on the geometry of the fault and the potential for Dinantian limestone occurrences at depths of 4-5 km, as well as Givetian-Frasnian (G-F) carbonates at shallower depths (2-3 km) in the Condroz region. Additionally, reprocessing and reinterpretation of the Dekorp 1A line indicated a strong potential for Dinantian carbonates at depths suitable for deep geothermal exploration in Eastern Belgium

Building on these promising results, the Walloon government has approvedurther large geophysical investigations in 2024. The WALSCAN project will gather approximately 400 km of seismic lines across three key areas: Charleroi, Liège, and Verviers/Eupen. Coordinated by GSB, WALSCAN brings together experienced partners like UMONS, ULG, and EPI Ltd, who contribute extensive expertise in geophysics, geothermal energy and regional geology. Scheduled for 2026, the seismic campaign will concentrate on identifying Dinantian carbonates at varying depths (1.5 km to 4 km) within densely urbanized areas, which align with regions of high energy demand.

1. INTRODUCTION

The Dinantian limestone formations in Wallonia are subdivided into three main geological domains: the Ardenne Allochthon (Dinant Synclinorium), the Brabant Parautochthon, and the deeply buried units located beneath the south-dipping Midi-Eifel Thrust Fault (METF). From Belanger et al. 2012, the Variscan front in Wallonia is divided in four main structural units: from north to south, 1) the Brabant Massif and its undeformed cover, 2) the Brabant Parautochthon, 3) the Haine-Sambre-Meuse thrust units (HSM-OTS), and 4) the Ardenne Allochthon. The Midi Fault is defined as the major tectonic boundary separating the parautochthonous units from the allochthonous thrust sheets.This major Variscan structure plays a key role in the regional architecture of the Paleozoic basement. It marks the northern limit of the Ardenne fold-and-thrust belt and has transported the Devonian–Carboniferous succession northward over the Brabant Massif during the Variscan Orogeny (Hance et al., 1999). Structural correlations between eastern and central Belgium and northern France confirm the presence of this large-scale overthrust, with an estimated displacement of up to 100 km in northern France (Anderle et al., 1991).

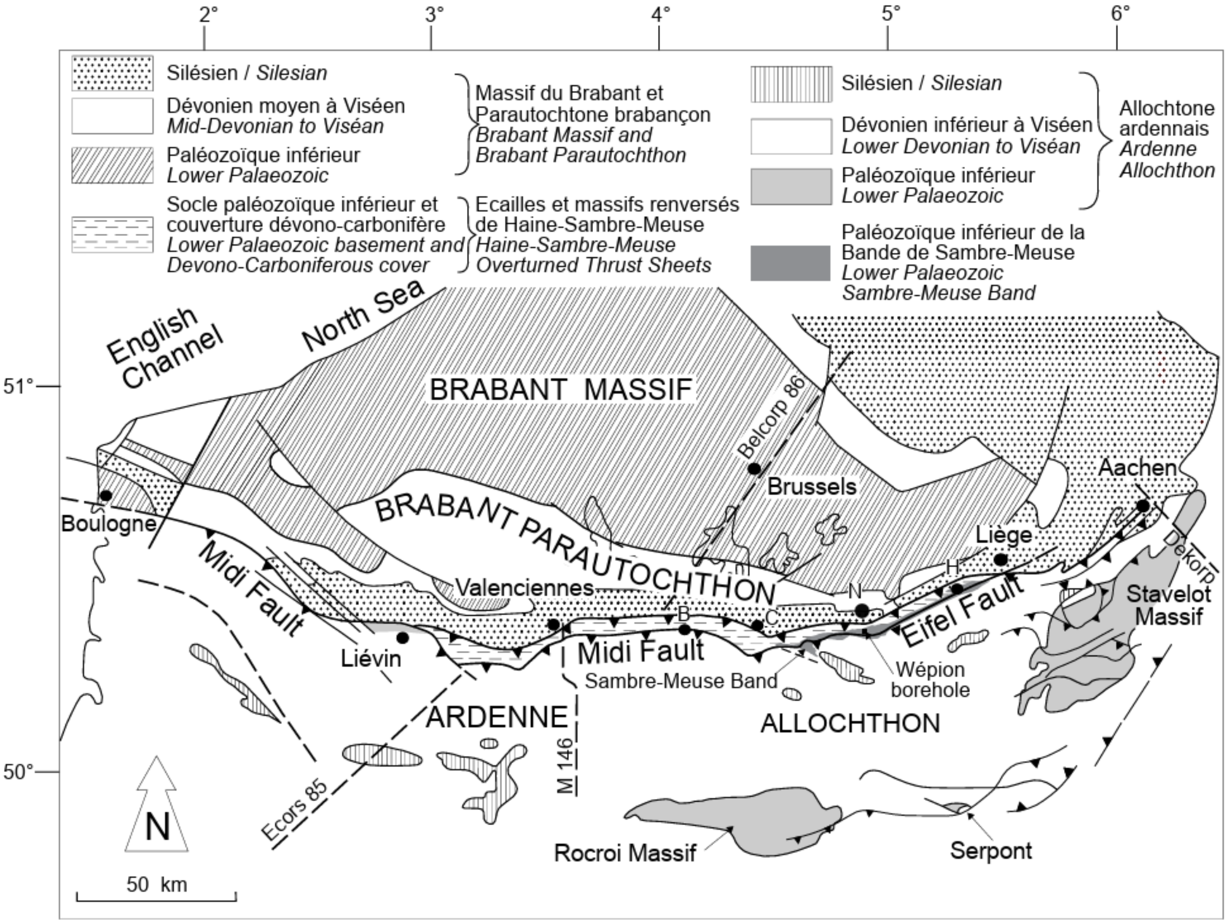

Figure 1: The Variscan Front within its lithostratigraphic context in Belgium and neighbouring countries; location of major seismic profiles (from Belanger et al. 2012, adapted from Hance et al., 1999). Abbreviations: B = Binche; C = Charleroi; H = Huy; N = Namur.

While the outcropping carbonate units of the Dinant Synclinorium are not suitable for deep geothermal exploitation due to their shallow depth and structural position, the Dinantian formations buried beneath the METF and the Upper Carboniferous along the central axis of the Brabant Parautochthon are considered potential targets. However, their southern extent, thickness, and structural configuration remain poorly constrained due to important tectonic complexity (intense faulting and folding, see Figure 2). The Figure 2 shows the resulting structural complexity map which clearly reflects the patterns identified on geological and tectonics base maps of North-West Europe. The three units that are differentiated are, in order of increasing structural complexity and therefore uncertainty: 1. Stable areas, gentle folding and faulting in yellow; 2. Horst and graben areas, inverted basins, complex faulting (normal/reverse) in light green. 3. Structurally complex areas with thrust sheets and nappes, intensely folded and faulted in blue.

Therefore, existing geological interpretations present significant divergences, highlighting the need for improved geophysical imaging and model calibration.

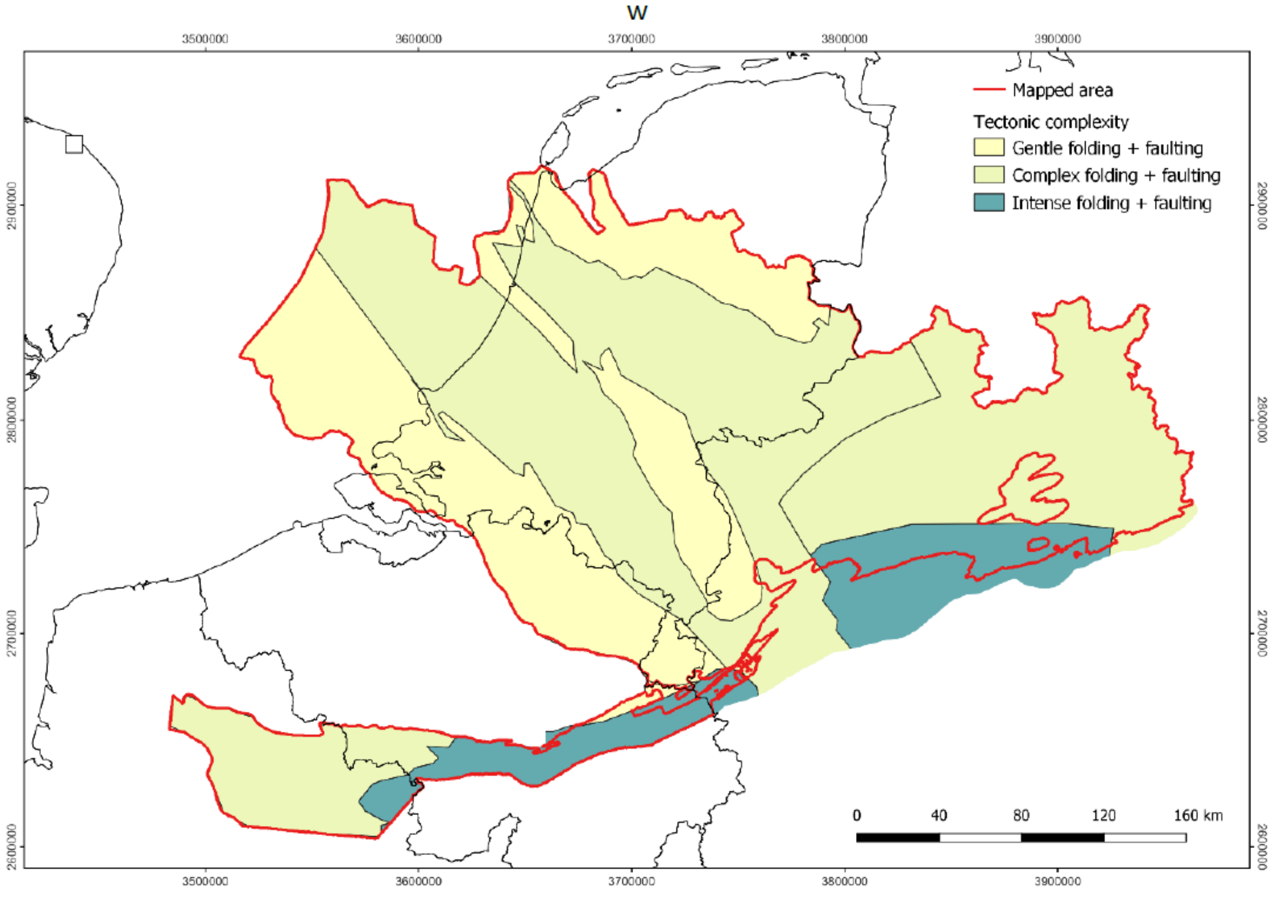

Figure 2 : Tectonic complexity of the Dinantian in the mapped region of Northwestern Europe, with an assessment of moderate, complex, and intense deformation (light yellow, yellow, and blue) from Veldkamp & Foeken, 2023.

2. OVERVIEW OF SEISMIC SURVEYS IN WALLONIA

Seismic reflection profiling in Wallonia has evolved significantly over the past five decades, transitioning from deep crustal and hydrocarbon exploration toward targeted geothermal assessment (see lines location on Figure 3). This evolution is marked by advances in acquisition systems, survey design, and interpretive goals. The current geological target is typically the Dinantian carbonate platform, variably buried and structurally complex across the Variscan front and adjacent domains. Campaigns prior to 2022 were characterized by legacy analog equipment, limited channel counts, and cable-based acquisition systems, while the most recent GEOCOND 2022 survey marked a shift to state-of-the-art nodal systems and modern processing techniques.

The earliest campaigns in the *Famenne* (1976–1978) and *Vesdre* (1978–1979) zones focused on areas at the northern margin of the Ardenne Allochthon, characterized by intense Variscan deformation, steeply dipping strata, and pronounced folding. Aimed at regional stratigraphic mapping and hydrocarbon exploration, these surveys consisted of several 2D profiles totaling approximately 50 km each. The Vesdre campaign, acquired by CGG using a Sercel SN338 analog system, employed 48 active channels, 80 m inter-trace spacing, and Mertz VS10 vibrators (15.5 klbs) with 12 s sweeps (12–62 Hz). While limited by their analog nature and narrow bandwidth, the profiles revealed consistent reflectors at ~1 s TWT, interpreted as potential carbonate horizons. These datasets have since been digitized and converted into SEG-Y format, offering opportunities for reprocessing and reinterpretation.

The BELCORP 1986 survey was a landmark crustal-scale experiment designed to image the deep continental lithosphere across Belgium. Acquired by Prakla-Seismos, the 132 km profile traversed the Variscan front from Jeumont (France) to the Campine basin near Turnhout (Belgium). Using a Sercel 348 system with 200 channels and four VVCA vibrators (27.5 klbs), the line employed 20-second sweeps (12–48 Hz). Technical limitations of the CS2502 correlator restricted usable listen time to 12 s, with early data (0–4 s) sacrificed in alternating shots. Despite these constraints, the southern section—reprocessed in 2012—provided valuable imaging of Dinantian structures beneath the parautochthonous Brabant unit. Challenges included urban noise, complex near-surface layering, and attenuation due to legacy coal mining voids.

The DEKORP87-1A profile forms part of the German DEKORP program and extends across eastern Belgium from Teuven to Monschau. Acquired in the 1980s with deep crustal objectives, the survey was reprocessed within the Interreg NWE DGE-ROLLOUT framework to enhance upper crustal imaging. The reprocessed DEKORP87-1A seismic profile, covering 93 km from eastern Belgium into western Germany, has revealed critical insights into the deep geological structure of the Variscan front (Arndt et al., 2023). Using modern seismic attributes and structural modeling, a prominent southeast-dipping reflector was identified beneath the Stavelot-Venn Massif. This reflector, marked by strong amplitudes and RMS anomalies, is interpreted as the top of the Dinantian carbonates at depths ranging from 2,500 to 4,000 m. Typical carbonate features such as clinoforms and karst collapse structures support this interpretation. The carbonates lie directly below the Aachen Thrust and were likely transported during major Variscan orogeny. This finding confirms the potential of Dinantian units as geothermal targets in eastern Belgium. However, the complexity of thrusting, restricted borehole availability for interpretation, and seismic data quality impose interpretational uncertainty.

The Mons 2012 and Hainaut 2019 surveys, led by the University of Mons, marked the first seismic campaigns in Wallonia specifically designed to evaluate deep geothermal potential. The lines cross the Midi-Eifel Thrust Fault (METF) and span the transition between the post-Variscan Mons Basin and the Variscan front. Acquired using a Sercel SN428 telemetry system, with 12-element 10 Hz geophone arrays and AHV-IV or M12 vibrators (45–61 klbs), the surveys applied 12–18 s linear sweeps ranging from 10–100 Hz. Although these campaigns improved resolution and target imaging (notably the Dinantian limestone and Midi-Eifel Thrust), they still suffered from limited bandwidth and cultural noise contamination, especially in urban areas. Notably, sweep tests performed in 2012 revealed the importance of lower starting frequencies and moderate sweep rates (ideally <5 Hz/s) to improve imaging at depths around 2 seconds TWT.

The GEOCOND 2022 campaign, conducted by the Geological Survey of Belgium, adopted the latest nodal acquisition technology (Stryde nodes) with 10 m receiver spacing and 20 m shot spacing. It featured 3 × 43 klb vibrators and sweep tests covering 4–80 Hz over 20 seconds with a listening period of 6 sec. These tests concluded that benefits plateau beyond 70 Hz, and that starting frequencies as low as 4 Hz help reduce wavelet ringyness. The campaign initially used two sweeps per VP but shifted to one sweep after 8 km due to lower-than-expected noise in rural areas. Data quality improved significantly due to higher trace density, broader bandwidth, and finer spatial sampling. However, persistent challenges included strong ground roll and source-generated noise, particularly near coherent structures.

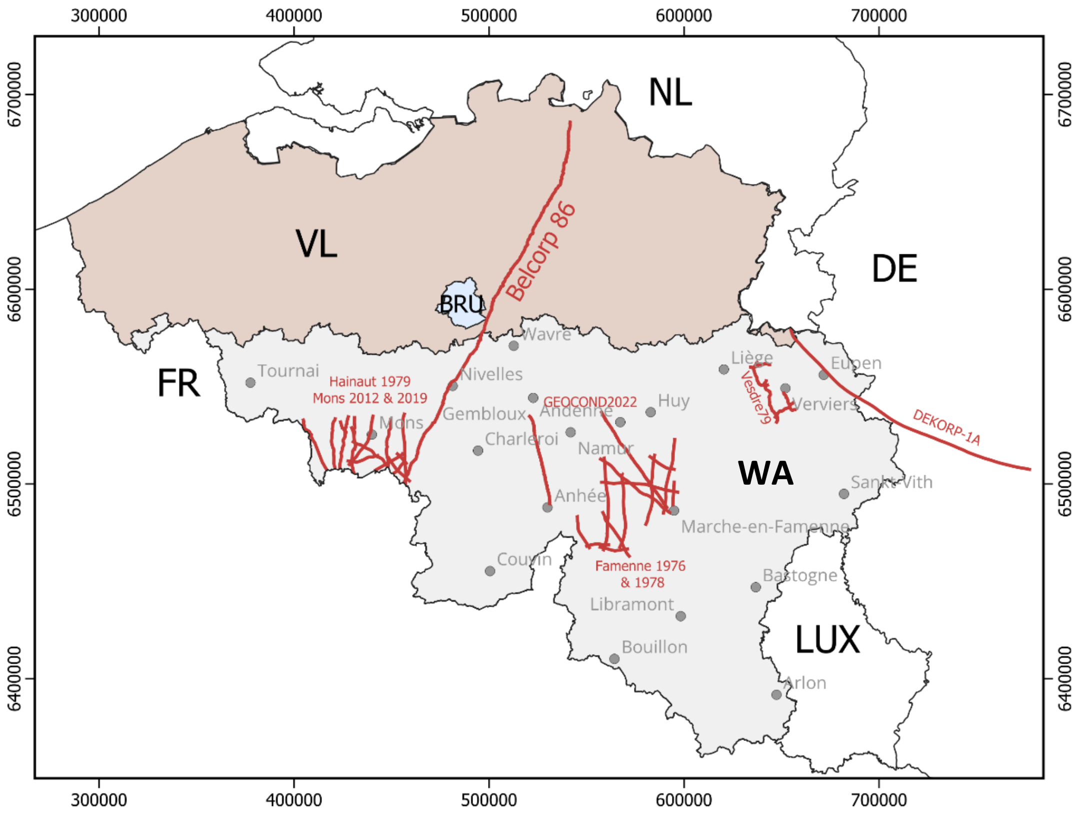

Figure 3: Location of the Walloon seismic lines from 1976 to 2022 (ETRS89-EPSG 3034).

3. RESULTS OF GEOCOND 2022

Co-funded by Interreg NWE, the Walloon Government, and the Royal Belgian Institute for Natural Sciences, this campaign aimed to verify the presence and depth of Dinantian carbonate reservoirs (330–360 Ma) beneath the Midi-Eifel Thrust Fault (METF) and initially refine imaging of the region's structural framework down to depths of 6 km.

Seismic data were acquired along two lines (L1 and L2, Figure 3), totaling about 63 km across 15 municipalities. The field operations involved 3,060 sensors and 3,027 vibration points, with dense receiver deployment and active engagement with over 1,200 landowners. The acquisition, carried out in 16 days (December 2022–January 2023), benefited from favorable subsurface conditions that enabled energy penetration into the mid-crust (about 15km), a major outcome in the structurally complex domain of the Variscan fold-and-thrust belt.

The processing phase faced multiple technical challenges, including irregular geometry, lateral velocity variations, and high ambient noise. Manual picking of first arrivals and advanced static corrections were necessary. A robust workflow combining non-linear refraction tomography (diving wave tomography), RMS velocity analysis, and Kirchhoff pre-stack time migration was implemented using GeoThrust and Reveal software.

These efforts resulted in improved imaging of deep reflectors and seismic facies (Figure 4 A and B), notably: 1) Clear identification of the Midi Fault structure, including its dip and shear zone : in the outcropping the METF zone has a slope of 57° to the South-East (in cyan on Figure 4B). 2) The main detachment horizon is located mainly near the angular unconformity between Lower Devonian rocks and the Lower Palaeozoic formations from the “Brabant Massif extension” or basement. 3) Some reflection packages in southern part of the lines, interpreted as Givetian–Frasnian (G-F) carbonate horses and Lower Devonian/Eifelian units (in orange on Figure 4B) , revealed potential shallower geothermal reservoirs (1–3 km depth). These units in the Condroz region may offer new opportunities for geothermal energy and should be evaluated further in future work. 3) Deeper discontinuous reflectors, possibly representing the Dinantian limestones at depth of 3-4km (in cyanon Figure 4B), suggesting that their southward extension under the METF in the central part of Wallonia is very restricted, especially in comparison with western and eastern parts of Wallonia. It results probably of a geometrical cocktail of shallow depth, thinner formations and steeply dipping thrust.

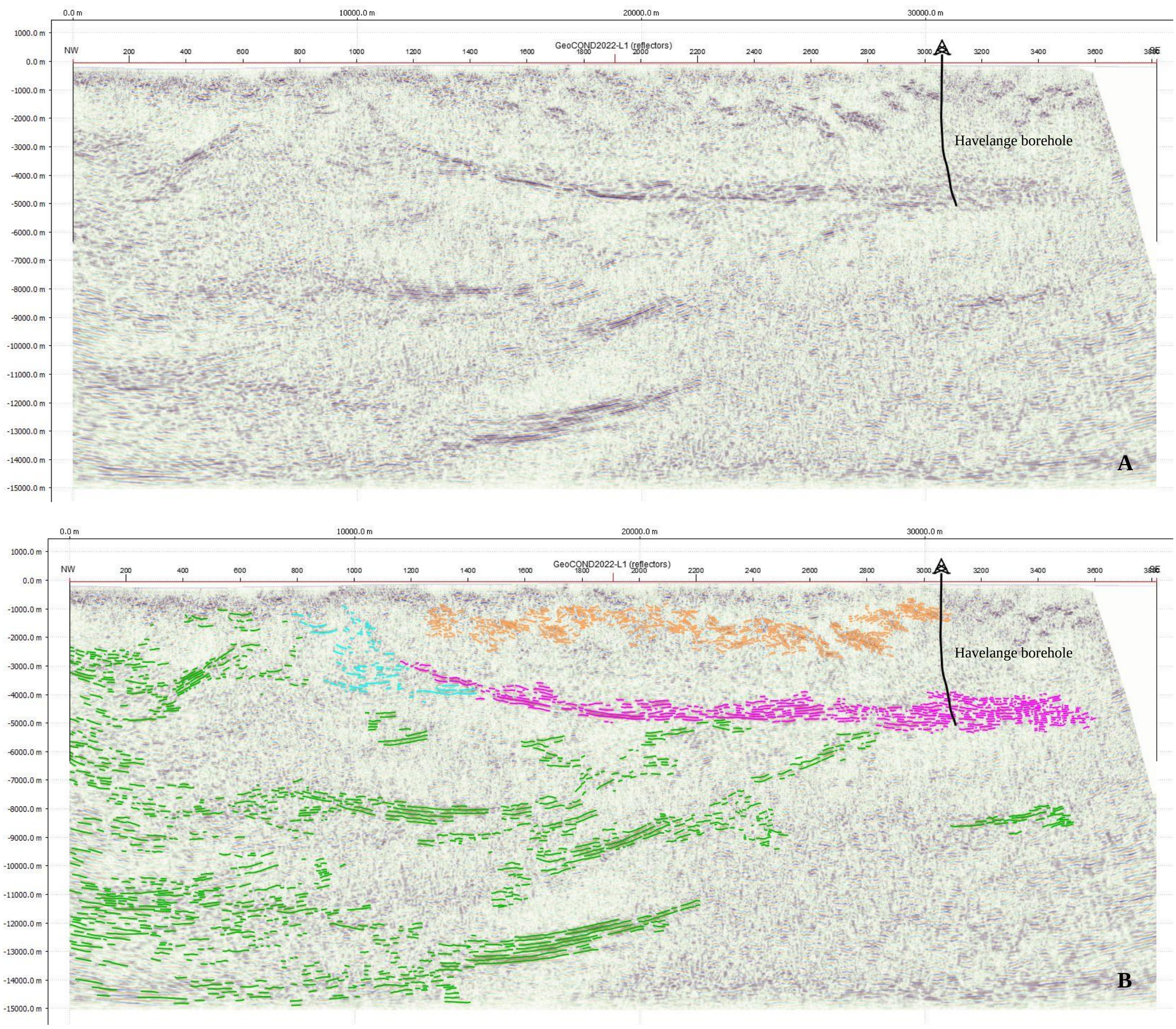

Figure 4 : GEOCOND L1 sections (A: the Post Stack Time Migration section; B: the PSTM with reflectors (Orange: Givetian–Frasnian limestones of the Allochthon, Pink: deep segment of the Midi Fault , Green: reflectors associated with the basement (probably Caledonian in age) , Blue: hanging wall of the Midi Fault near its surface expression, defined by the truncation of reflectors against the fault and their contact with the overlying Lower Devonian).

As part of the DGE-ROLLOUT project, the reprocessing of DEKORP87-1A line and the two new seismic reflection lines (GEOCOND22) have yielded valuable insights into the geothermal potential of the Dinantian. Mapping efforts have focused on estimating the depth and thickness of the Dinantian along the central axis and northern flank of the Brabant Parautochthon, using data sources that vary with local geological structure and composition.

Figure 5 presents the updated bottom surface map of the Dinantian carbonate units in Wallonia, incorporating results from the GEOCOND22 seismic survey and harmonization efforts with neighboring regions (Hauts-de-France and North Rhine-Westphalia). The mapping reveals a refinement of the southern extent and geometry of the Dinantian beneath the Midi-Eifel Thrust Fault, particularly in the Namur area. The integration of new reflection data enabled the adjustment of structural boundaries and depth estimations in previously uncertain zones, helping to delineate geothermal targets at depths ranging from 3 to 5 km. At this stage, the model provides a satisfactory assessment of resource distribution from the French-German border, with a few areas where data scarcity prevents the development of a realistic model. These poorly-constrained zones lack both direct and indirect observational data and correspond to regions of significant tectonic complexity and intense deformation, particularly in the Charleroi, Liège and Verviers-Eupen areas.

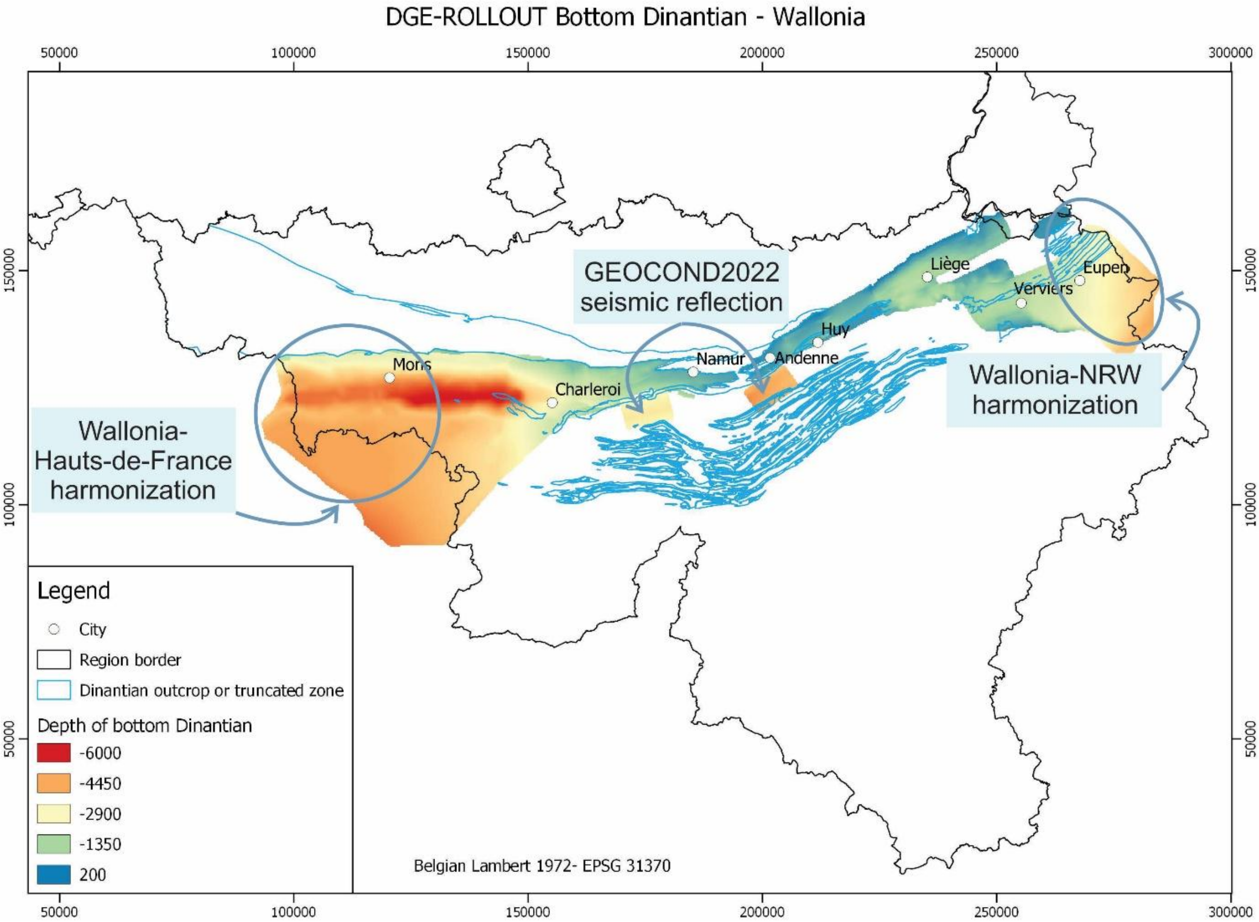

Figure 5 : Map of the Dinantian bottom in Wallonia with the delimitation of the updates following the seismic reflection survey GEOCOND2022 and the transborder harmonization efforts with the Hauts-de-France region and North Rhine-Westphalia (NRW).

4. WALSCAN PROJECT

The WALSCAN 2026 seismic campaign, financed by the Public Service of Wallonia and, coordinated by the Geological Survey of Belgium (RBINS) in collaboration with ULiège, UMons, EPI Ltd (UK), and the Royal Meteorological Institute, forms a key component of Wallonia's strategy to accelerate the deployment of deep geothermal energy. Scheduled as part of the Walloon Recovery Plan, the campaign aims to acquire between 360 km and 460 km of new 2D seismic reflection profiles across three structurally contrasting zones: Charleroi, Liège, and Verviers–Eupen. These areas were selected based on their geothermal interest and the presence at varying depths, of the Dinantian carbonate formations and the high energy demand in a region of high population density.

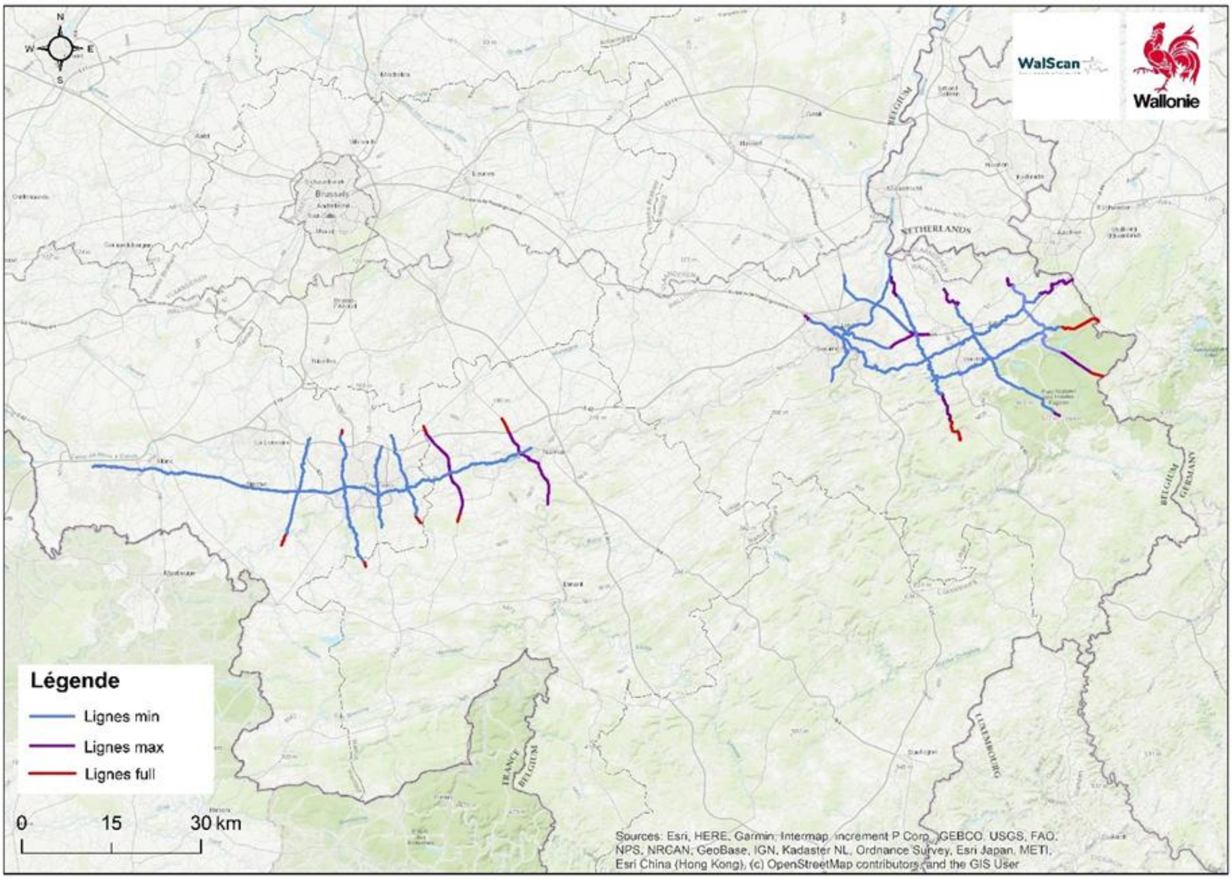

Figure 6: Provisional WALSCAN pre-plots with full version (in red: 460km), maximum version (in purple: 430km) and minimum version (in blue: 360km).

The primary objective is to characterize the depth, thickness, and internal structure of the Dinantian units, which are expected between 400 and 4,000 metres depending on the zone. The Charleroi sector targets carbonate platforms typically buried between 1,600 and 4,000 m, with estimated reservoir thicknesses ranging from 800 to over 2,000 m. In contrast, the Verviers–Eupen zone exhibits high structural complexity, with the top of the Dinantian anticipated at depths exceeding 3,000 m and reduced carbonate thicknesses. The Liège area is characterized by a shallower and more fragmented Dinantian unit, generally located between 400 and 1,500 m and displaying limited lateral continuity.

The total length of seismic lines to be acquired will depend on the selected acquisition parameters. Accordingly, three provisional pre-plot scenarios were defined : a minimum version of 360 km (in blue on Figure 6), which is secured; a maximum version extending beyond this base (in purple on Figure 6); and a full version representing the most extensive coverage (in red on Figure 6). Additional segments from the maximum and full versions will be activated in 10km increments and will be included based on available funding and operational feasibility.

In the future work, the seismic acquisition will face major challenges like deep targets in Charleroi and Eupen areas, steeply dipping reflectors in fold-and-thrust belt settings, high cultural noise in very dense populated areas, and strong lateral velocity variations. The proposed strategy aims to balance signal penetration, noise suppression, and spatial resolution in structurally complex zones of the WALSCAN zones of interest.

5. CONCLUSIONS

The GEOCOND22 seismic campaign demonstrated the feasibility of acquiring high-resolution seismic data across structurally complex regions of the Variscan fold-and-thrust belt in central Wallonia. The processed sections provided improved imaging of the Midi-Eifel Thrust Fault and revealed reflection packages that may correspond to Dinantian carbonates at depths of 3 to 4 km, as well as shallower G-F units between 1 and 3 km in southern part of the lines. However, interpretation remains highly uncertain due to the lack of control wells in the surveyed area even if the Havelange borehole (depth of 5,6km) brought crucial information for G-F reflectors and shared zone of METF identification in southern part of Line 1. As a result, lithological identification and depth calibration rely exclusively on seismic facies, regional correlations, and structural assumptions. These limitations underscore the need for future validation via drilling to confirm the presence and characteristics of the targeted carbonate reservoirs. The upcoming WALSCAN campaign will aim to reduce these uncertainties and extend the investigation into higher-demand areas such as Charleroi, Liège, and Eupen.

The extensive regional exploration WALSCAN campaign is a key milestone in Wallonia's broader strategy to develop deep geothermal energy. As outlined in the region's *Plan Air Climat Énergie* (PACE), achieving carbon neutrality by 2050 will require the diversification of renewable heat sources, including geothermal systems. Deep geothermal energy, in particular, has been identified as a strategic lever for decarbonizing heating in dense urban areas and industrial hubs. By improving geological knowledge and reducing uncertainties related to the subsurface, current seismic studies are laying the foundation for future investments, risk mitigation measures, and regulatory planning necessary for the emergence of a viable deep geothermal sector in Wallonia.

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